

APPENDIX E

**AN ACTUARIAL APPROACH TO DEVELOPMENT
OF SAFETY-RELEVANT CRITERIA FOR
IN-VEHICLE DEVICE USE**

BY

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APPENDIX E. AN ACTUARIAL APPROACH TO DEVELOPMENT OF SAFETY-RELEVANT CRITERIA FOR IN-VEHICLE DEVICE USE

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1. INTRODUCTION

The Task 4 Interim Report (Wierwille, Tijerina, Kiger, Rockwell, Lauber, and Bittner, 1992) outlined an actuarial approach to establishing the safety relevance of in-vehicle device workloads (pp. 1-10 to 1-12). The concept, fundamentally, was to examine an accident data base and then attempt to relate it to in-vehicle task demands. The concept is an extension of Perel's (1976) approach to accident narrative search.

A block diagram of the proposed procedure was presented in the Task 4 Interim Report, which became the guiding philosophy in carrying out the approach. However, small changes were made as the analysis proceeded. Figure 1 shows the revised block diagram of the analysis procedure. The database search procedure has been previously reported in a technical paper (Wierwille and Tijerina, 1993) to which the reader is referred. The results of the four blocks on the left side of Figure 1 are contained in that technical paper. The remainder of the steps depicted in the block diagram are presented herein. These steps emphasize the exposure analysis aspects (right-hand column of Figure 1) as well as the combining of data base search and exposure analysis work (bottom two blocks of Figure 1).

In carrying out the exposure analysis, emphasis was placed on visual demands of in-vehicle devices. While visual workload is not the only form of driver workload, it is by far the most important. Because of the relatively coarse nature of accident data base analyses, it appeared that attempting to introduce other forms of workload, at least in this first analysis, would be unwarranted and unlikely to provide any additional insight.

This paper is organized in accordance with Figure 1, with sections in sequence from the top right to the bottom center of the figure. The earlier technical paper (Wierwille and Tijerina, 1993) is referred to whenever needed and should be on hand when reading this paper.

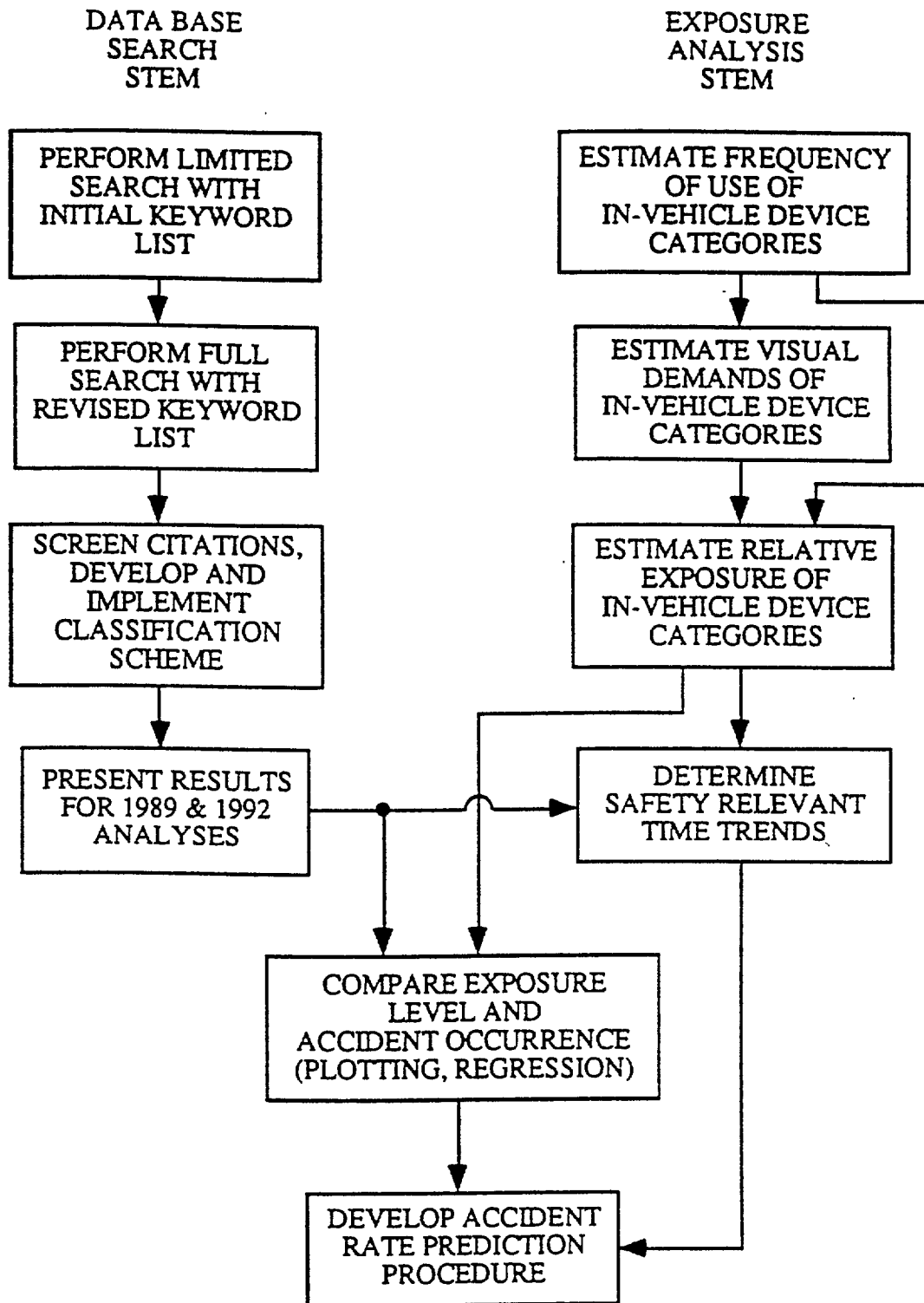


Figure 1. Revised Block Diagram of the Actuarial Approach to Establishing Safety Relevance

2. ESTIMATING FREQUENCY OF USE OF DEVICE CATEGORIES

It must be recognized that various in-vehicle devices are used with different frequencies. For example, the speedometer is used frequently, whereas map reading is performed infrequently. The accident statistics are likely to reflect a combination of frequency of use and the cost in driver resources per use. In fact, it is reasonable to assume that the product of these two factors is reflected in the accident data. Thus, both factors must be taken into account.

The analysis described in this section is limited to devices that appear on almost every production automobile. If a device exists only on a small fraction of vehicles, it must be handled separately. Its exposure is lower than that of devices appearing on most vehicles. Such low-production devices are analyzed separately in Section 6 of this paper.

Three sources of information were found on frequency of use. The first of these is a paper presented at the Transportation Research Board by Bhise, Forbes, and Farber (1986). Although the text of the paper was never published, copies of the transparencies used for the presentation were obtained from the authors. One of the transparencies contained information on usage as shown in Table 1. These data, were gathered using an instrumented vehicle in which drivers' eye and hand positions were videotaped while they drove. The right column in Table 1 has been added to the authors' table, because usage per week of driving is more easily interpreted than usage per year.

The second source of data was found by Michael Perel of NHTSA. A report by Woodson, Conover, Miller, and Selby (1969) of Man Factors, Inc., contains data on relative frequency of use. The data were obtained by observing and recording usage occurrences in three actual driving situations: freeway, suburban, and urban. The average of these occurrences yielded the relative frequency count information shown in Table 2. As can be seen the usage data contain information on some items that are not in the instrument panel per se. Furthermore, it is not clear from the text whether the data include visual reference only or visual reference and manual manipulation. Nevertheless, the data do provide some relative information on usage. The third source is that developed from questionnaire data obtained by Anacapa Sciences (1976). The data are summarized in Table 3. These are the only known questionnaire data available and are in a form that requires further processing before they can be ranked, or placed in frequency-of-use form. To accomplish ranking, it was necessary to weight the various columns. The following weighting equation was developed and used:

$$\begin{aligned}\text{Relative use value} = & 20X (\% \text{ at least once a day}) \\ & + 5X (\% \text{ at least once a week}) \\ & + (\% \text{ at least once a month})\end{aligned}$$

The results of the weighting procedure appear in Table 4, with data arranged from highest to lowest values. As can be seen, the relative weighting does include results in a ranking of usage that seem to coincide with intuition.

Table 1. Relative usage of various in-vehicle devices (Bhise, Forbes, and Farber, 1986). (The right column has been added for ease of interpretation.)

INSTRUMENT PANEL DEVICE	USAGE PER YEAR	USAGE PER WEEK
SPEEDOMETER	48,000	920
TURN SIGNAL	5,300	102
RADIO CONTROLS	2,900	56
CLIMATE CONTROLS	1,900	37
WINDSHIELD WIPERS	1,500	29
FUEL GAGE	1,300	25
HEADLAMP SWITCH	500	10

Table 2. Relative usage of various in-vehicle devices (Woodson, Conover, Miller, and Selby (1969).

DEVICE	RELATIVE USAGE
Braking	65
Steering	61
Accelerator	33
Turn signal control	33
Turn signal indicator	33
Rear view mirror	31
Gear selector control	11
Gear selection indicator	11
Speedometer	10
Ignition switch	7
Engine instruments	4
Windshield wiper/washer	3

Table 3. Summary of frequency of use data from Anacapa studies (1976)

ITEM	RATED FREQUENCY OF USE					
	% AT LEAST ONCE A DAY	% AT LEAST ONCE A WEEK	% AT LEAST ONCE A MONTH	% SEASONALLY	% RARELY OR NEVER	% NOT IN MY CAR
Headlight	54.6	38.4	4.3	0.1	2.6	0
Wiper	3.2	22.5	43.5	2.5	28.2	0.1
Radio	76.2	9.5	1.8	0.1	6.1	6.3
Heater	5.3	14.7	31.1	7.0	40.4	1.4
Defroster	4.6	13.4	29.0	4.7	43.8	4.5
Cigarette Lighter	19.3	5.4	1.8	0.0	58.7	14.8
Ashtray	28.8	6.3	3.7	0.0	58.6	2.7
Hazard Flasher	3.5	3.8	9.3	0.1	67.4	15.9
Air Vent	48.4	20.6	9.4	2.4	16.2	3.0

Table 4. Results of the weighing procedure applied to the Anacapa data.

DEVICE	RELATIVE WEIGHTING
Radio	1573
Headlights	1288
Air Vent	1080
Ashtray	611
Lighter	415
Heater	221
Wiper	220
Defroster	188
Hazard Flasher	98

To take full advantage of the three sources of data, it is necessary to combine them. Doing so, however, requires some interpretation, because the same information does not appear in all three sources. For the Anacapa data, the categories of air vent, heater, and defroster were temporarily combined to form an equivalent "climate controls" category. Similarly the lighter and ashtray categories were combined to form a lighter/ashtray category. In regard to the Woodson, et al., data, certain categories were temporarily deleted, namely those associated with braking, steering, and accelerator. With these modifications, it becomes possible to perform a relative fit of the three sources, as shown in Table 5. As can be seen in the table, anchor points of radio, climate control, and wiper or wiper/washer can be made to align with one another. Then, items can be arranged around these rankings to complete the table.

It is clear from the table that a conflict exists for turn signals and speedometer. The Woodson et al., data show the turn signals to have the highest ranking, whereas the Bhise et al., data show the speedometer to have the highest ranking. Obviously, differences could be a result of scenario or driving environment differences. However, it does seem inconsistent with intuition that the speedometer would be used nine times more often than the turn signals (Bhise et al.) in any type of situation except straight road. Thus, some modification of the Bhise, et al., data for speedometer usage seems to be justified.

In addition, a conflict exists between the Anacapa and Bhise et al., data in regard to the headlamps. If beam switching is included, then the Anacapa data appear reasonable, whereas, without it the Bhise et al., data appear reasonable.

The data in Table 5 can now be used in developing a single graphical representation, as shown in Figure 2. In the graph, average usage per week is shown logarithmically from highest usage at the top to lowest usage at the bottom. The usage numerical values are based primarily on the Bhise et al., data, which are the only absolute data available. (Both the Woodson et al. and Anacapa data are relative data.) When conflicts in ranking exist, they have been resolved by examining the conflict and making prudent adjustments. In the case of headlamps, values are supplied for use with beam switching and without. Hazard flashers have been estimated on the basis that a driver might use them once every five weeks. Figure 2 represents the best available estimates on frequency of use for the items shown.

Unfortunately, the usage items shown in Figure 2 do not correspond exactly with the accident categories developed during the data base search. Consequently, further interpretation is necessary. To begin the process, categories for which data are needed must be determined. This can be accomplished by listing the categories appearing in the data-base search analysis, considering only those for which it is possible to estimate frequency of use. (An example of a category for which frequency of use data cannot be obtained is "interaction with another person or animal in vehicle.") Once the relevant categories are listed, their frequency of use can be estimated by comparison with (and interpolation of) the data in Figure 2. As in the case of previous analysis, estimation and judgment are necessary to complete the frequency-of-use

Table 5. Best fit of frequency-of-use data from three sources.

ANACAPA	Woodson, et al.	Bhise, et al.
	Turn-Signals 33	Speedometer 920
	Mirrors 31	
	Speedometer 10	Turn-Signals 102
Radio 1573	-----	Radio 56
Climate 1479	-----	Climate 37
Headlamp 1288		
Lighter/Ashtray 1026	Engine Inst. 4	
Wiper 220	-----Wiper/Washer----- 3	Wiper 29
		Fuel Gage 25
		Headlamp 10
Hazard 98		

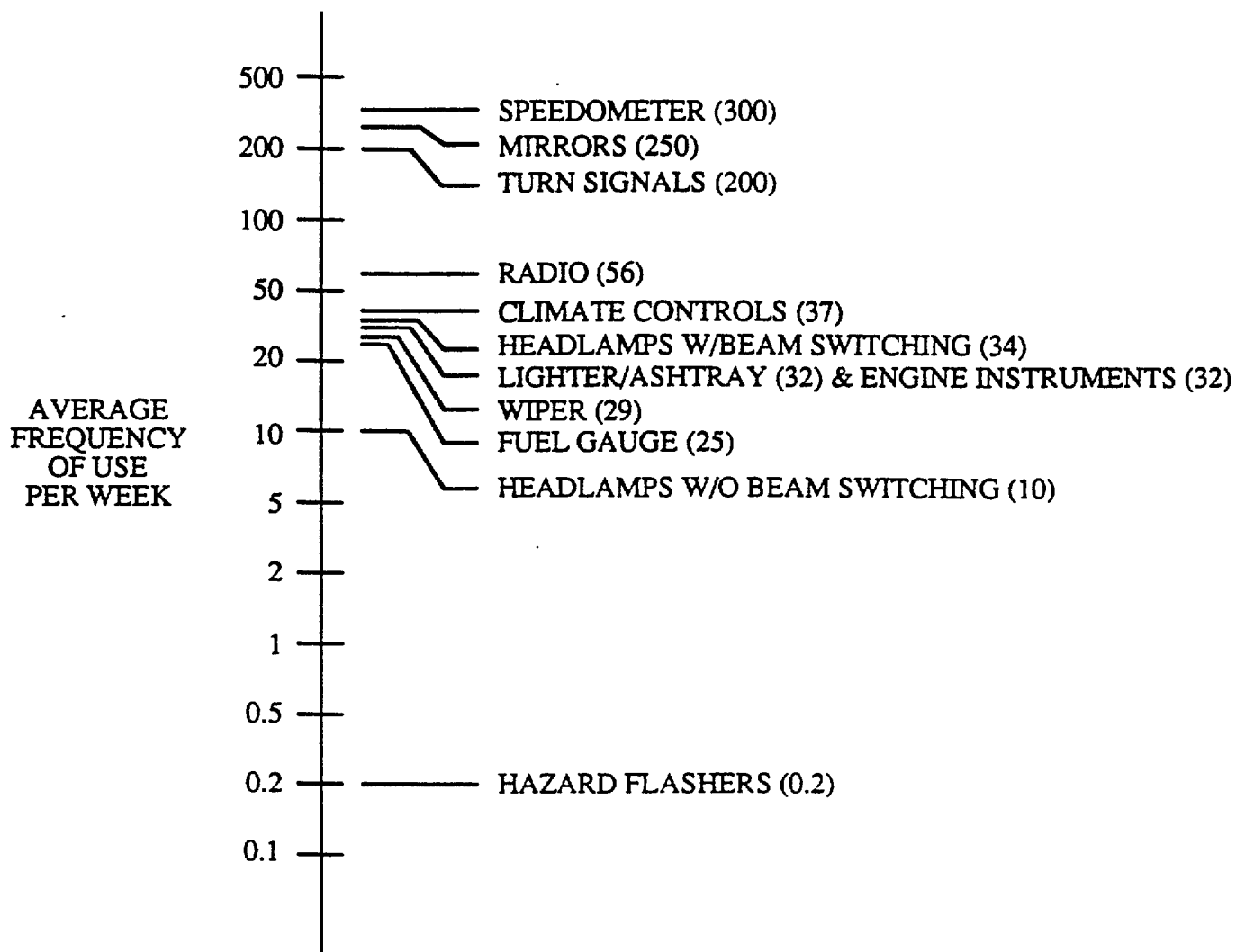


Figure 2. Composite frequency of use chart based on available data and prudent interpretation.

analysis. Table 6 contains the results, with frequency of use listed in descending order. The table has been developed assuming that the vehicle is in motion. The table is the culmination of all analysis work on frequency of use, relevant to the accident data base search.

It should be noted that the category of "turn signals" has been deleted from Table 6. Turn signal-related accidents could not be searched because there were more than 10,000 citations. Many accidents involve failure to signal, or signaling inappropriately. The narratives for these could not be separated from narratives for accidents in which the driver's attention was diverted by using turn signals or checking the turn signal indicators. Similarly, hazard flashers could not be examined because many "non-workload" accidents involve hazard flashers. The categories listed in Table 6 are ones for which accident occurrence data have been obtained.

3. ESTIMATING VISUAL DEMAND OF DEVICE CATEGORIES

There are several good sources of data on the visual demands created by in-vehicle devices. These have been previously reviewed and presented in Chapter 2.0 of the Task 4 Interim Report (Wierwille et al., 1992), as well as in Wierwille (1993). The reader is referred to these documents for a more comprehensive review. In this analysis of visual demands, three sources were used. The first (Rockwell, 1987) provides glance duration information for radios and for mirrors and is summarized in Table 7. The second source is that of Bhise et al. (1986) and is summarized in Table 8. It consists of glance duration and number of glances required for speedometer, fuel gauge, clock, radio, and multiple pushbuttons. The third source is the most comprehensive (Dingus, Antin, Hulse, and Wierwille (1989), as shown in Table 9. It contains information for a variety of conventional in-vehicle tasks and also for navigation tasks using an in-car display. The three references, taken together provide a good background on which to base visual demand estimates.

When the three sources are examined, it becomes clear that the agreement is excellent. Accordingly, all three can be used in estimating visual demands of device categories for which accident data exist. Because the Dingus et al. data are the most comprehensive, they have been relied upon most heavily. The other two sources (Bhise et al., and Rockwell) can be used to supplement the Dingus et al., data.

It must be mentioned that visual demand of in-vehicle devices involves two important parameters, as discussed in Wierwille (1993), namely, mean single glance time and mean number of glances, required to service the in-vehicle device. Both parameters are needed to obtain an estimate of visual demand.

The results of the visual demand estimation process appear in Table 10. The data are presented in the same order as the ranked frequency-of-use data (Table 6). Both mean single glance times and mean number of glances have been estimated.

Table 6. Listing of items from accident data base categorization analysis and estimated frequency of use (while the vehicle is in motion).

Category	Frequency of Use/Week
Speedometer	300
Mirrors	250
Standard Radio	56
Climate Controls	37
Smoking/Lighting	32
Wiper/Washer	29
Fuel Gauge	25
High Beam Indicator	24
Clock	15
Vent	15
Heater & Air Conditioner	15
Lock, Side Window, and Related Hardware	15
Visor	12
Gearshift	10
Defroster/Defogger	7
Seat Belt	5
Seat	3
Personal Timepiece	3
Map	1

Table 7. Summary of glance duration data for conventional tasks (Rockwell, 1987).

	Study	# Runs	x	Median	s	5%	95%
RADIO	A	35	1.27	1.20	.48	.82	2.16
	B	100	1.28	1.29	.50	.89	1.83
	C	72	1.42	1.30	.42	.80	2.50
LEFT MIRROR	A	35	1.06	.96	.40	.80	.20
	*B	100	1.22	1.15	.28	.94	1.80
	C	72	1.10	1.10	.33	.70	1.70

* Commanded mirror looks of discrimination.

Note: All data given in seconds.

Table 8. Summary of results presented by Bhise, Forbes, and Farber (1986).

<u>Tasks Requiring a Single Glance</u>	
Task	Mean Glance Duration (Seconds)
Read Analog Speedometer	
• Normal	0.4 to 0.7
• Check	0.8
• Exact Value	1.2
Read Analog Fuel Gauge	1.3
Read Digital Clock	1.0 to 1.2

<u>Tasks Requiring Several Glances</u>		
Task	Number of Glances	Mean Glance Duration (Seconds)
Turn on Radio, Find Station, Adjust Volume	2 to 7	1.1
Read all Labels on a 12-Button Panel	7 to 15	1.0

Table 9. Average length and number of in-car glances for a variety of conventional and navigation tasks (Dingus et al., 1989).

Task	In-car Single Glance Length		Number of Glances	
	Mean	Standard Deviation	Mean	Standard Deviation
Speed	0.62	0.48	1.26	0.40
Following Traffic	0.75	0.36	1.31	0.57
Time	0.83	0.38	1.26	0.46
Vent	0.62	0.40	1.83	1.03
Destination Direction	1.20	0.73	1.31	0.62
Remaining Fuel	1.04	0.50	1.52	0.71
Tone Controls	0.92	0.41	1.73	0.82
Info. Lights	0.83	0.35	2.12	1.16
Destination Distance	1.06	0.56	1.73	0.93
Fan	1.10	0.48	1.78	1.00
Balance	0.86	0.35	2.59	1.18
Sentinel	1.01	0.47	2.51	1.81
Defrost	1.14	0.61	2.51	1.49
Fuel Economy	1.14	0.58	2.48	0.94
Correct Direction	1.45	0.67	2.04	1.25
Fuel Range	1.19	1.02	2.54	0.60
Cassette Tape	0.80	0.29	2.06	1.29
Temperature	1.10	0.52	3.18	1.66
Heading	1.30	0.56	2.76	1.81
Zoom Level	1.40	0.65	2.91	1.65
Cruise Control	0.82	0.36	5.88	2.81
Power Mirror	0.86	0.34	6.64	2.56
Tune Radio	1.10	0.47	5.91	2.39
Cross Street	1.66	0.82	5.21	3.20
Roadway Distance	1.53	0.65	5.78	2.85
Roadway Name	1.63	0.80	6.52	3.15

Note: Glance length given in seconds.

Table 10. Estimated visual demand parameters for categories appearing in the accident data base analysis. (Order is the same as that in Table 6.)

Category	Mean Single Glance Time	Mean Number of Glances
Speedometer	0.62	1.26
Mirrors	1.00	1.00
Standard Radio	1.20	3.50
Climate Controls	1.10	1.75
Smoking/Lighting	1.50	4.00
Wiper/Washer	1.10	1.20
Fuel Gauge	1.30	1.20
High Beam Indicator	0.62	1.00
Clock	0.83	1.26
Vents	0.62	1.83
Heater & Air Conditioner	1.10	1.75
Lock, Side Window, and Related Hardware	1.40	1.60
Visor	0.80	2.00
Gearshift	1.50	1.75
Defroster/Defogger	1.10	1.20
Seat Belt	1.50	2.00
Seat	1.50	2.50
Personal Timepiece	0.83	1.26
Map	1.70	5.00

Note: Mean single glance length in seconds

It should be mentioned that some categories involve multiple activities. For example, for standard radio, the driver might simply adjust the volume, or the driver might tune the radio to a specific digital frequency. The former requires little in the way of visual demand, whereas the latter requires a great deal. Thus, for such a category, an average visual glance time and an average number of glances must be estimated.

4. DETERMINE EXPOSURE LEVEL OF IN-VEHICLE DEVICES

There are no set standards for determining exposure level caused by in-vehicle devices. However, researchers have long suspected that any time the driver's resources are allocated to invehicle devices, there is an increase in exposure (that is, an increase in the likelihood or risk of being involved in an accident). Indeed the main reason for examining the visual demands of invehicle devices has been the tacit assumption that the greater such demands are, the more likely it is that their use will result in an accident.

The two previous sections have been directed at obtaining the components that should go into an exposure level estimate, namely visual demand and number of times a device is used per unit time (say, for example, per week). It would seem reasonable that the exposure should be related to the visual demand per se multiplied by the frequency of use.

As previously indicated, visual demand can be assessed in terms of two parameters, mean single glance time and mean number of glances. These two parameters are important because drivers ordinarily perform visual sampling to complete in-vehicle tasks. Both parameters are needed to obtain an assessment of visual demand.

To a first approximation the product of mean single glance time and mean number of glances equals mean total glance time. This is the total visual glance time that is needed to service the in-vehicle device each time it is used. Correspondingly, total glance time can be multiplied by frequency of use to assess exposure. In terms of the parameters, exposure then becomes:

$$\text{TYPE 1 EXPOSURE} = \left(\begin{array}{c} \text{mean} \\ \text{single-glance} \\ \text{time} \end{array} \right) \times \left(\begin{array}{c} \text{mean} \\ \text{number of} \\ \text{glances} \end{array} \right) \times \left(\begin{array}{c} \text{frequency} \\ \text{of} \\ \text{use} \end{array} \right)$$

This exposure represents the total time that the driver's eyes are allocated to the in-vehicle device, say, per week (while the vehicle is in motion). This type of exposure has been called Type I to distinguish it from two additional types that are yet to be described.

Type I exposure involves the assumption that a glance into the vehicle of, say, 1.6 seconds involves a risk or exposure that is exactly twice as great as that of a glance into the vehicle of 0.8 second. In other words, exposure increases linearly with mean single-glance time. Such an assumption may not be fully warranted, however. It can be argued that exposure increases more

rapidly than a simple linear function of mean single glance time, because longer eyes-off-road times substantially increase the likelihood of not detecting a hazard in the forward view, or at least of not detecting a hazard soon enough to prevent an accident. Thus, it is argued that mean single glance time should enter the exposure assessment with substantially heavier weighting for longer times. Two alternative types of exposure are thus defined, one in which mean single glance time is taken to the three-halves power and one in which it is taken to the second power (that is, it is squared) as shown in the following equations:

$$\begin{aligned}\text{TYPE 2 EXPOSURE} &= \left(\frac{\text{mean}}{\text{single-glance}} \right)^{3/2} \times \left(\frac{\text{mean}}{\text{number of}} \right) \times \left(\frac{\text{frequency}}{\text{of}} \right) \\ &\quad \left(\frac{\text{time}}{\text{glances}} \right) \times \left(\frac{\text{use}}{\text{use}} \right) \\ \text{TYPE 3 EXPOSURE} &= \left(\frac{\text{mean}}{\text{single-glance}} \right)^2 \times \left(\frac{\text{mean}}{\text{number of}} \right) \times \left(\frac{\text{frequency}}{\text{of}} \right) \\ &\quad \left(\frac{\text{time}}{\text{glances}} \right) \times \left(\frac{\text{use}}{\text{use}} \right)\end{aligned}$$

All three types of exposure are carried through the remainder of the analysis.

Using Tables 6 and 10, it is possible to calculate all three types of exposure for the accident data base categories. The results appear in Table 11.

5. RELATING EXPOSURE LEVEL TO ACCIDENT OCCURRENCE

All of the relevant information has now been developed to allow plotting of accident occurrence as a function of exposure level for various accident categories. Accident occurrence data are presented in Figures 1 through 15 of Wierwille and Tijerina (1993). These figures are for 1989, as previously described. They represent a full year of accident data base results and are probably the most accurate accident occurrence data available. Exposure data are contained in Table 11 (of this paper) for the three types of exposure.

For Type 1 and Type 2 exposures, regression analyses were conducted. These are shown in Figures 3 through 6. Figure 3 shows the plot of accident occurrence vs. exposure, the corresponding regression line, and the 95% confidence limits on the regression line for all of the Type 1 exposure data. As can be seen in the figure, all of the data points except one fall near the regression line, indicating qualitatively that there is a relationship between exposure and accident occurrence. The slope of the regression line is significantly different from zero, $p = 7.7 \times 10^{-8}$. The correlation coefficient associated with the data is $R = 0.898$, which is also significant, $p < 0.00001$. (It should be mentioned that two points in the graph are not plotted because they fall on top of existing points. Thus, 19 values are plotted with only 17 points appearing.)

The outlying point is that associated with the speedometer. The speedometer is used very often, but does not appear to cause as many accidents as the regression line would seem to predict.

Table 11. Exposure values for categories appearing in the accident data base analysis.

Category	Exposure*		
	Type 1	Type 2	Type 3
Speedometer	234	185	145
Mirrors	250	250	250
Standard Radio	235	257	287
Climate Controls	77	75	80
Smoking/Lighting	192	235	288
Wiper/Washer	38	40	42
Fuel Gauge	39	44	51
High Beam Indicator	15	12	9
Clock	16	14	13
Vents	17	13	11
Heater & Air Conditioner	29	30	32
Lock, Side Window, and Related Hardware	34	40	47
Visor	19	17	15
Gearshift	26	32	39
Defroster/Defogger	9	10	10
Seat Belt	15	18	22
Seat	11	14	3
Personal Timepiece	3	3	3
Map	9	11	14

* Values are rounded to the nearest integer.

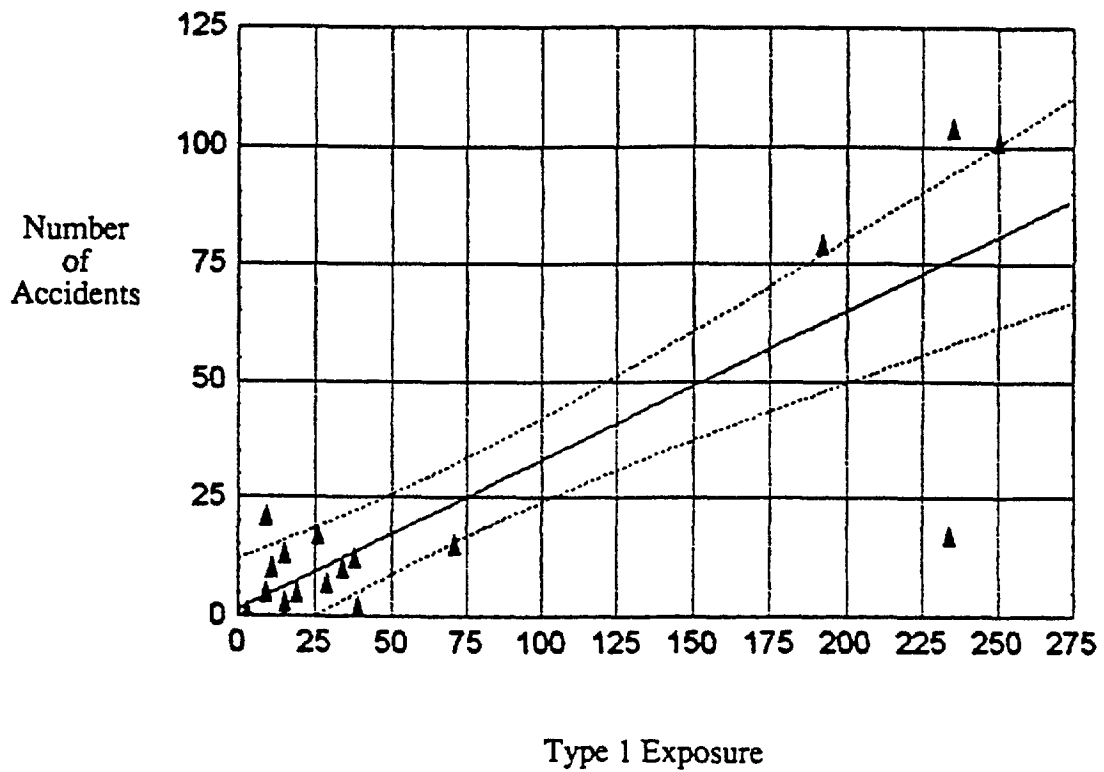


Figure 3. Plot of accident occurrence vs. Type 1 exposure, with regression line and 95% confidence limits shown.

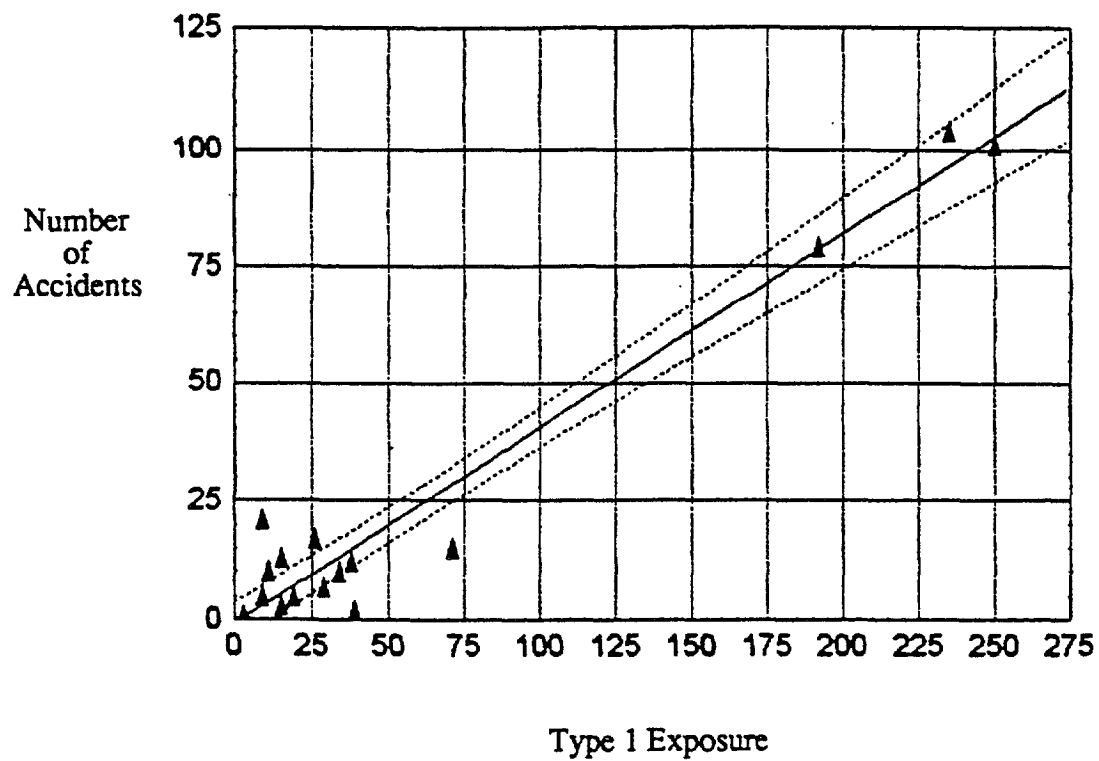


Figure 4. Plot of accident occurrence vs. Type 1 exposure, with regression line and 95% confidence limits shown. (Outlier removed from data set.)

This under-representation may be a result of the prime location of the speedometer directly below the forward line of sight, and also a result of the overlearned usage of the speedometer.

Because of the appearance of the speedometer outlier, the regression analysis for Type 1 exposure was rerun with this point removed. The result appears in Figure 4. As can be seen, there is a much better fit of the regression line to the data and the 95% regression line confidence limits are now much narrower. The slope of the regression line is of course significantly different from zero, $p = 6.35 \times 10^{-14}$, and the corresponding correlation coefficient is now 0.982 which is also significant, $p < 0.000001$.

The corresponding results for Type 2 exposure are shown in Figures 5 and 6. Figure 5 shows results with the outlier included, and Figure 6 shows them with the outlier deleted. In Figure 5 the slope is significantly different from zero, and the corresponding correlation coefficient is 0.941 which is significant. Similarly in Figure 6, the slope of the regression line is significantly different from zero, and the corresponding correlation coefficient is 0.982 which is significant.

For Type 3 exposure, no attempt was made at linear regression, because the plotted data clearly showed a nonlinear trend. This nonlinearity is even more pronounced when the outlier point for speedometer is included. Accordingly, an analytical function was developed by trial and error and is shown along with the plotted data in Figure 7. The curve shown has the equation

$$Y = 0.185X_3 + 0.1e^{0.0223X_3}$$

where X_3 is the Type 3 exposure value and Y is the corresponding level of accident occurrence. It should be noted in Figures 3, 5, and 7 that the outlier point moves closer to the other data as exposure goes from Type 1 to Type 2 to Type 3. This is a result of the short mean single glance time for the speedometer. When this smaller glance time is taken to the three-halves power or second power, it reduces the corresponding value of exposure, causing the point to move to the left when plotted, relative to most of the other points.

6. SAFETY RELEVANT TIME TRENDS

Additional accident trend information can be obtained by directly comparing the 1989 and 1992 accident occurrences by category. Three such comparisons are presented here: cellular telephone-related, standard radio-related, and special radio-related.

The Cellular Telecommunications Industry Association (CTIA) has estimated that in 1989 there were 3.5 million cellular telephone users. They have similarly estimated that in 1992 there were 11 million such users, a very substantial increase. Figure 11 of Wierwille and Tijerina (1993) shows that there were 11 cellular phone accidents in 1989 and Figure 18 of that paper shows that

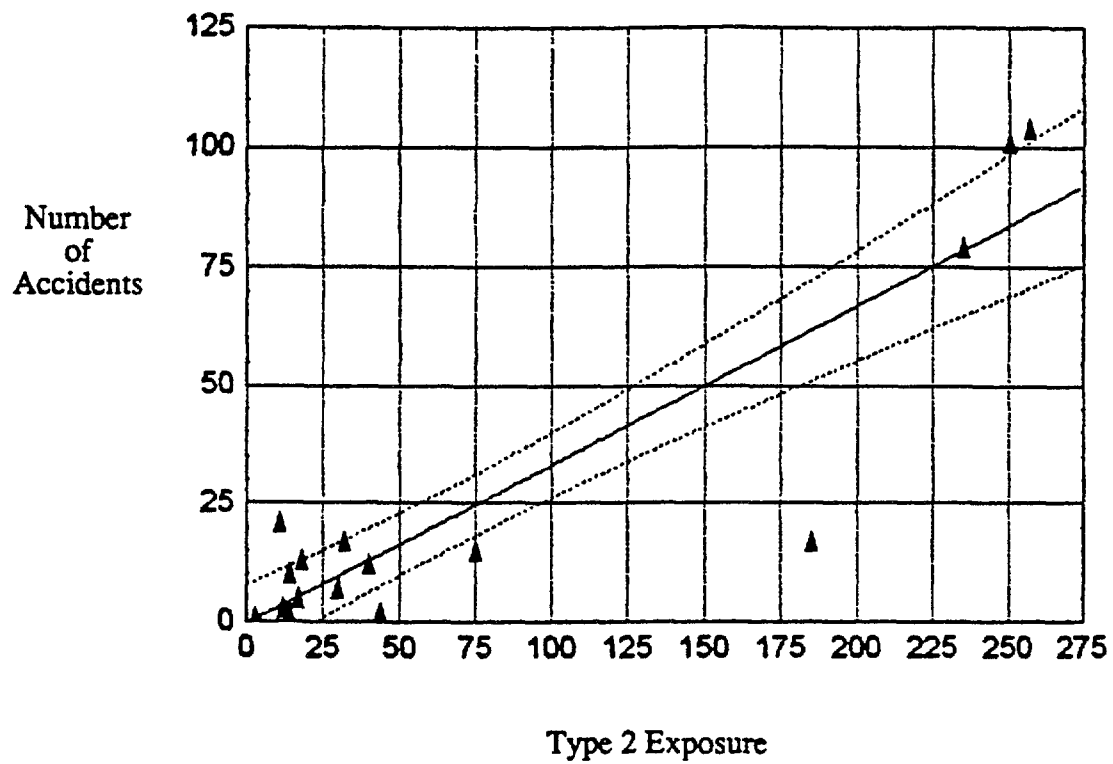


Figure 5. Plot of accident occurrence vs. Type 2 exposure, with regression line and 95% confidence limits shown.

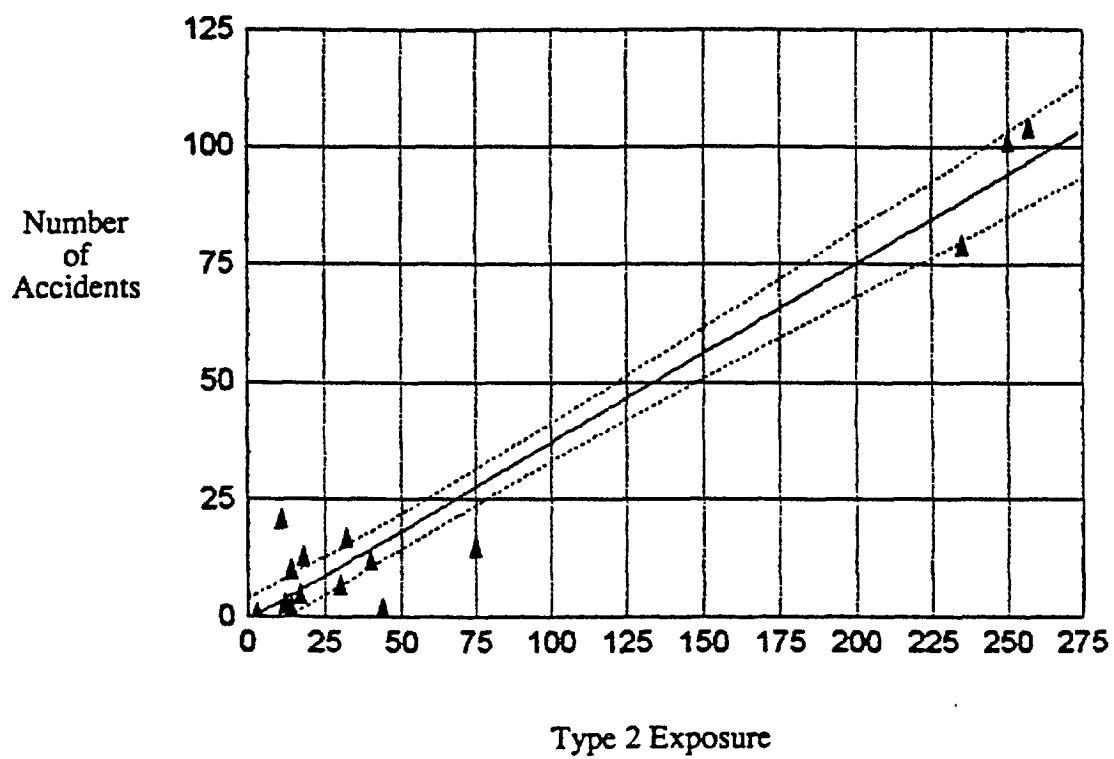


Figure 6. Plot of accident occurrence vs. Type 2 exposure, with regression line and 95% confidence limits shown. (Outlier removed from data set.)

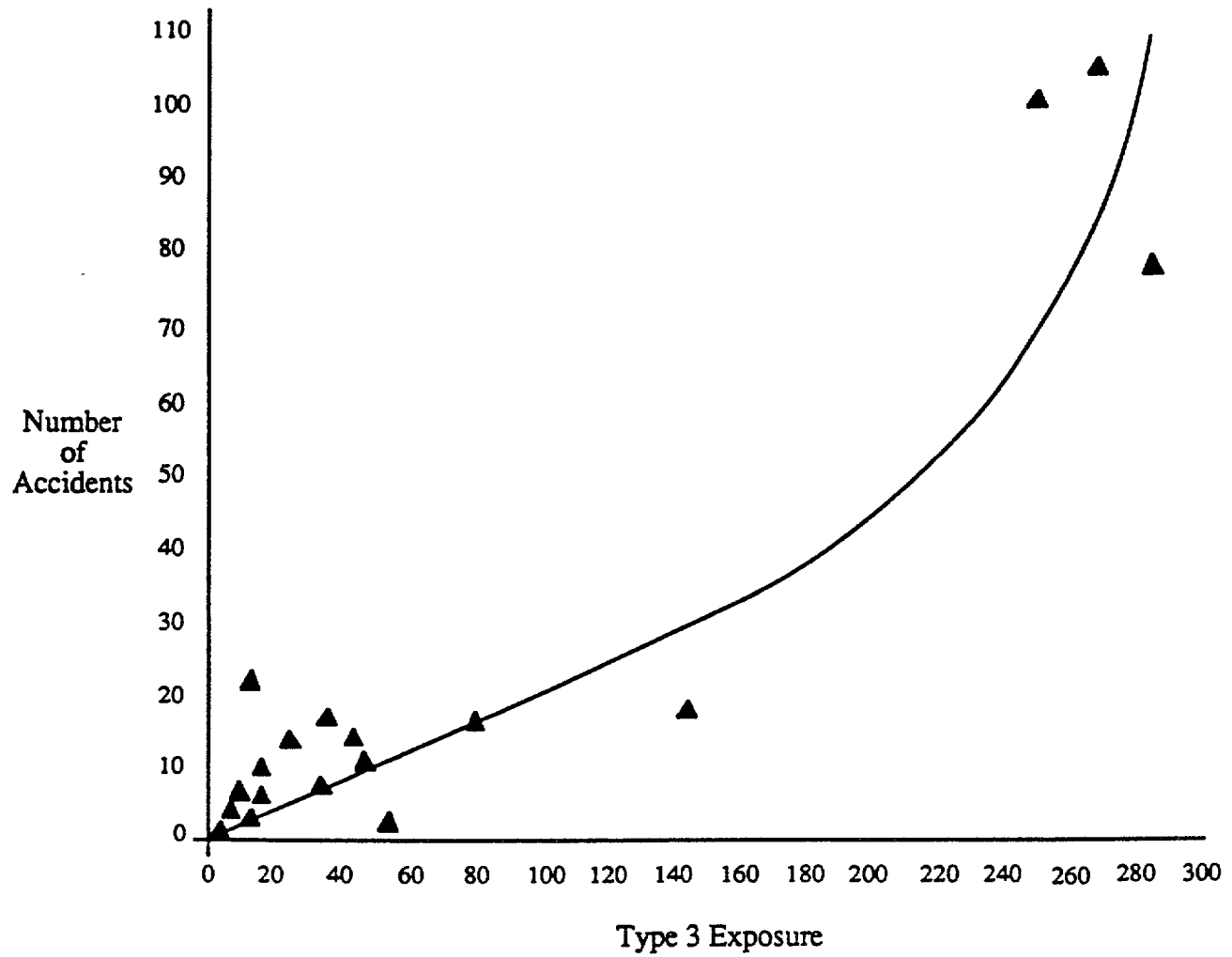


Figure 7. Plot of accident occurrence vs. Type 3 exposure, with analytical curve fitted to the data.

there were estimated to be 27 in 1992. Figure 8 herein compares those data in plotted form. It is very clear from the figure that the number of accidents associated with cellular phones is rising rapidly as the number of these devices increases in the vehicle population. For standard radio-related accidents, data can be obtained from Figures 5 and 16 of Wierwille and Tijerina (1993). The data are compared herein in Figure 9 and suggest that there may be a slight increase in accident occurrence between 1989 and 1992. This trend could be a result of the increasing complexity of recent vehicle radios, which may be inducing somewhat greater visual demands on the driver.

Finally, special radio-related accident data are presented in Figures 6 and 17 of Wierwille and Tijerina (1993) and are compared here in plotted form in Figure 10. While the data are sparse, there appears to be a decreasing trend in special radio-related accidents. This trend may be a result of the apparent decline in the popularity of CB radios over the last several years. No figures were found for CB usage. However, it is probable that their use did decline between 1989 to 1992.

7. PREDICTION OF ACCIDENT OCCURRENCE

The previous analyses and data make it possible to predict the expected number of accidents that will occur when a new device is introduced into the vehicle population. There are several ways of doing this, and each would result in slightly different estimates. To avoid unnecessary complexity, a specific procedure has been developed and is presented here.

In examining the regression lines presented earlier, it is clear that Type 2 exposure provides the best fit to the data (Figure 6). Accordingly, the accident occurrence prediction model is based on Type 2 exposure. In Figure 6, the slope of the regression line is 0.375 accident per exposure unit. The regression line very nearly passes through zero. Thus, the number of accident narratives cited in North Carolina is 0.375 times the Type 2 exposure value for the in-vehicle device.

The steps for prediction are then as follows:

1. Determine the mean single glance time and the mean number of glances required to service the in-vehicle device.
2. Determine the number of times per week that the device is likely to be used by the average user.
3. Calculate the Type 2 exposure:

$$\text{TYPE 2 EXPOSURE} = \left(\frac{\text{mean single-glance time}}{\text{time}} \right)^{3/2} \times \left(\frac{\text{mean number of glances}}{\text{glances}} \right) \times \left(\frac{\text{frequency of use}}{\text{per week}} \right)$$

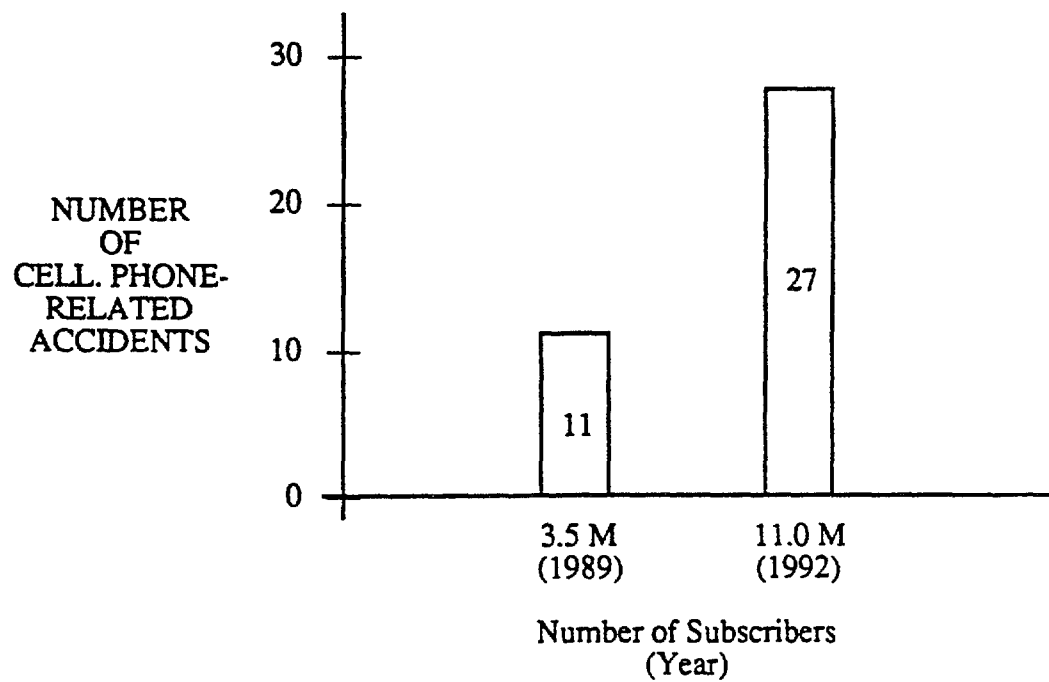


Figure 8. Number of cellular phone-related accidents as a function of number of subscribers in millions (also, years).

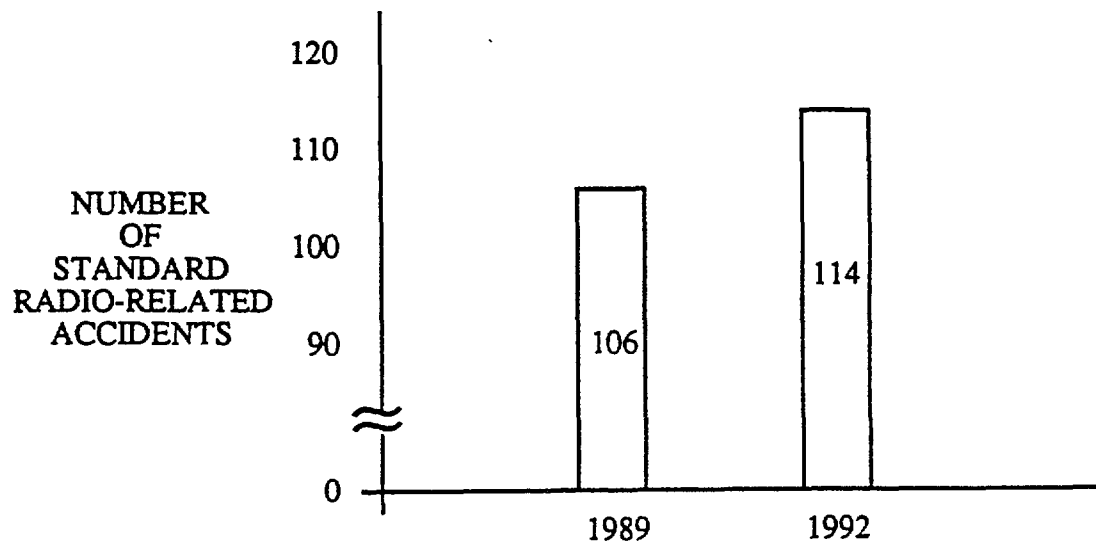


Figure 9. Number of standard radio-related accidents as a function of year.

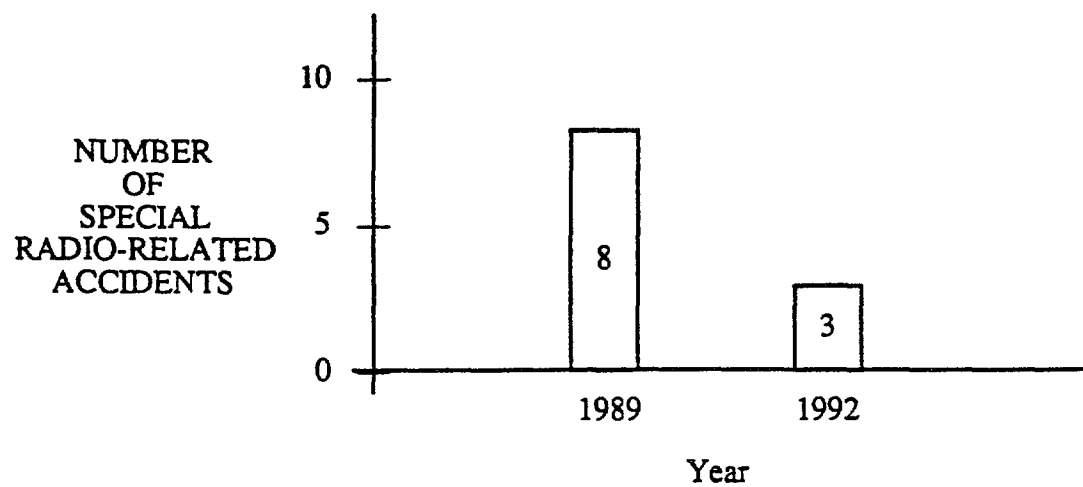


Figure 10. Number of special radio-related accidents as a function of year.

4. Calculate the number of accident narratives that would be projected to appear in North Carolina (which is assumed to be a typical state.)

$$\begin{array}{l} \text{Number of} \\ \text{occurrences,} \\ \text{N.C.} \end{array} = 0.375 \times \left(\begin{array}{l} \text{Type 2} \\ \text{Exposure} \end{array} \right)$$

5. Multiply the number of occurrences in North Carolina by 50 to estimate the occurrences nationwide.

$$\begin{array}{l} \text{Number of} \\ \text{occurrences,} \\ \text{U.S.} \end{array} = 50 \times \left(\begin{array}{l} \text{Number of} \\ \text{occurrences,} \\ \text{N.C.} \end{array} \right)$$

6. The result in 5. is based on the assumption that approximately 90 % of all vehicles would have the device installed. If more or fewer have the device, a correction must be made as follows:

$$\begin{array}{l} \text{Number of} \\ \text{occurrences, U.S.} \\ \text{corrected for} \\ \text{availability} \end{array} = \left(\begin{array}{l} \text{Number of} \\ \text{occurrences,} \\ \text{U.S.} \end{array} \right) \times \left(\begin{array}{l} \% \text{ of vehicles} \\ \text{equipped} \\ 90 \end{array} \right)$$

As an example of the accident occurrence prediction procedure, consider the following hypothetical example:

A traffic advisory display is to be introduced widely in the U.S. The display has been determined to require a mean single glance time of 1.35 seconds and to require 3.0 glances per use. Furthermore, it is expected that the device would be used 20 times per week. By 1998, it is anticipated that 30 % of all vehicles would have such devices installed.

For this example, the Type 2 exposure is

$$\begin{array}{l} \text{TYPE 2} \\ \text{EXPOSURE} \end{array} = (1.35)^{3/2} (3.0) (20) = 94$$

The corresponding N.C. occurrences (for 90 % of vehicles so equipped) is

$$\begin{array}{l} \text{Number of} \\ \text{occurrences,} \\ \text{N.C.} \end{array} = 0.375 (94) = 35$$

The corresponding U.S. occurrences (for 90% of vehicles so equipped) is

$$\begin{array}{l} \text{Number of} \\ \text{occurrences, U.S.} \end{array} = 50 (35) = 1750$$

and

The corresponding U.S. occurrences, corrected for availability is

$$\begin{array}{l} \text{Number of} \\ \text{occurrences, U.S.} \\ \text{corrected for} \\ \text{availability} \end{array} = 1750 \left(\frac{30}{90} \right) = 583$$

The procedure described in this section does not take into account the fact that many accidents cannot be attributed directly to a specific device. Figure 1 of Wierwille and Tijerina (1993), shows that many accidents involving visual allocation cannot be classified. Therefore, it must be remembered that predicted values are necessarily conservative and that the actual number of accidents attributed to a given in-vehicle device may be much greater than the value obtained from steps 4, 5, and 6 of the estimation procedure. Nevertheless, the procedure can be particularly helpful from a relative standpoint. The previous example for a traffic advisory display could, for example, be compared with standard radio usage to determine the relative likelihood of accidents with such a device.

8. CONCLUSIONS

The analyses contained in this paper provide a compelling argument that the amount and frequency of visual attention to in-vehicle devices is directly safely relevant. The clustering of data about the regression line relating exposure, particularly Type 2 exposure, to accident occurrence provides a powerful argument that the relative number of accidents is directly related to visual resource allocation for in-vehicle tasks. Considering the "noise level" associated with actuarial data, it is surprising that the results obtained are as good as they are. It should be mentioned that the data and analyses that have been presented are as unbiased as they could be made. All "exposure" values were computed before any plotting was done, and no exposure value was ever changed to make it "fit" closer to the trend. In other words, the analyses were performed with the philosophy of "let the chips fall where they may."

It should be obvious that many interpretations and assumptions were necessary in completing the analyses. These were unavoidable because of differences in data sets and data gathering techniques. Such assumptions and interpretations need to be carefully questioned and may require some later revision. Nevertheless, small changes in assumptions and interpretations are not likely to alter the main outcomes of the analyses.

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